US011776984B2

(12) **United States Patent**
Bouthinon

(10) **Patent No.: US 11,776,984 B2**
(45) **Date of Patent: Oct. 3, 2023**

(54) **IMAGE SENSOR COMPRISING AN ANGULAR FILTER**

(71) Applicant: **ISORG**, Limoges (FR)

(72) Inventor: **Benjamin Bouthinon**, Grenoble (FR)

(73) Assignee: **ISORG**, Limoges (FR)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 91 days.

(21) Appl. No.: **17/440,001**

(22) PCT Filed: **Feb. 20, 2020**

(86) PCT No.: **PCT/FR2020/050317**
§ 371 (c)(1),
(2) Date: **Sep. 16, 2021**

(87) PCT Pub. No.: **WO2020/193889**
PCT Pub. Date: **Oct. 1, 2020**

(65) **Prior Publication Data**

US 2022/0173153 A1 Jun. 2, 2022

(30) **Foreign Application Priority Data**

Mar. 22, 2019 (FR) 19/02965

(51) **Int. Cl.**

H01L 27/146	(2006.01)
G02B 5/00	(2006.01)
H10K 30/30	(2023.01)

(52) **U.S. Cl.**
CPC ***H01L 27/14643*** (2013.01); ***G02B 5/003*** (2013.01); ***H10K 30/30*** (2023.02)

(58) **Field of Classification Search**
CPC ... H01L 27/14643; H10K 30/30; G02B 5/003
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

10,165,211	B1	12/2018	Borthakur et al.
2004/0012734	A1	1/2004	Yamanaka et al.
2006/0061861	A1	3/2006	Munro et al.
2007/0045632	A1	3/2007	Oliver et al.
2008/0291445	A1	11/2008	Iwane
2009/0323206	A1	12/2009	Oliver et al.
2011/0233383	A1	9/2011	Oku

(Continued)

FOREIGN PATENT DOCUMENTS

EP	3441859	A1	2/2019
FR	3060811	A1	6/2018

(Continued)

OTHER PUBLICATIONS

English Translation of the Written Opinion of the International Search Authority issued in counterpart PCT application No. PCT/FR2020/050317, dated May 15, 2020, 6 pp.

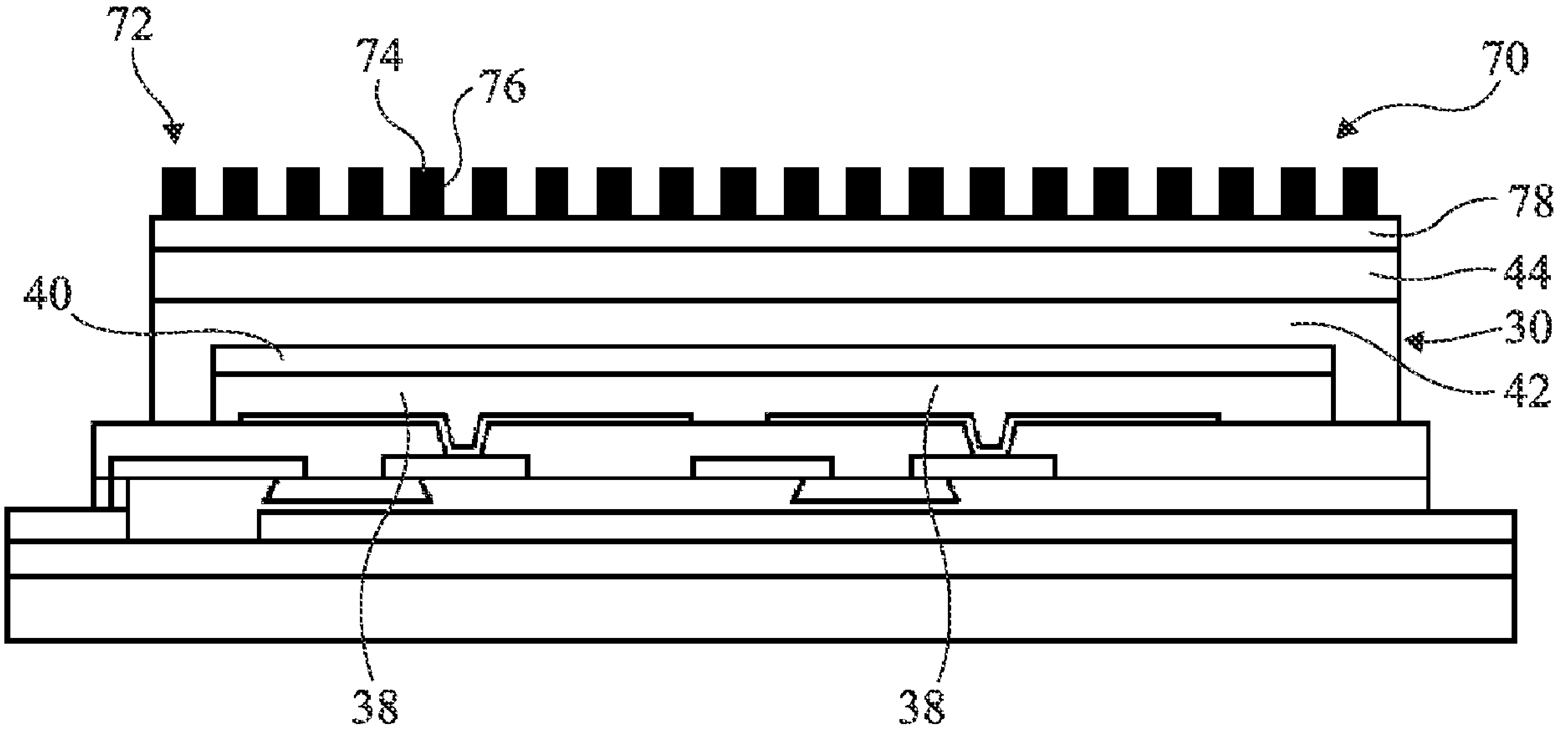
(Continued)

Primary Examiner — Thanh Luu
(74) *Attorney, Agent, or Firm* — KAPLAN BREYER SCHWARZ, LLP

(57) **ABSTRACT**

An image sensor includes organic photodetectors and an angular filter less than 20 µm away from the photodetectors. Further, a method of manufacturing an image sensor includes the forming of organic photodetectors and of an angular filter less than 20 µm away from the photodetectors.

20 Claims, 5 Drawing Sheets



(56) References Cited

U.S. PATENT DOCUMENTS

2014/0253756	A1*	9/2014	Yokogawa	H04N 25/135 348/229.1
2017/0084655	A1	3/2017	Shibuta	
2018/0288298	A1*	10/2018	Lim	H01L 27/14645
2019/0081098	A1	3/2019	Lenchenkov et al.	
2019/0148434	A1	5/2019	Hsu	
2022/0317351	A1	10/2022	Verduci et al.	
2023/0003923	A1	1/2023	Schwartz et al.	

FOREIGN PATENT DOCUMENTS

GB	0165893	A	7/1921
KR	10-2004-0090640	A	10/2004
WO	2014/042178	A1	3/2014
WO	2014/143234	A1	9/2014
WO	2014/181643	A1	11/2014
WO	2017/095858	A1	6/2017
WO	2018/162842	A1	9/2018
WO	2018/223150	A1	12/2018
WO	2019/055771	A1	3/2019

OTHER PUBLICATIONS

Authorized Officer: Fratiloiu, Silvia, International Search Report issued in counterpart PCT application No. PCT/FR2020/050317, dated May 15, 2020, 3 pp.

Benjamin Bouthinon et al., Unpublished Related U.S. Appl. No. 17/798,859 entitled Structure of an Angular Filter On a CMOS Sensor, Aug. 10, 2022.

Non-Final Rejection dated May 10, 2023 for U.S. Appl. No. 17/798,859, 5 page(s).

Authorized Officer: Jakober, Francois, International Search Report issued in PCT application No. PCT/EP2020/084543, dated Feb. 17, 2021, 2 pp.

Authorized Officer: Mollenhauer, Ralf, International Search Report issued in PCT application No. PCT/EP2021/053011, dated Apr. 16, 2021, 2 pp.

Authorized Officer: Orignac, Xavier, International Search Report issued in PCT application No. PCT/EP2020/075049, dated Nov. 3, 2020, 2 pp.

Authorized Officer: Orignac, Xavier, International Search Report issued in PCT application No. PCT/EP2020/085380, dated Jan. 13, 2021, 2 pp.

Benjamin Bouthinon et al., Related Unpublished US Patent Application filed Jun. 9, 2022, entitled "Optical Filter Suitable for Correcting the Electronic Noise of a Sensor", U.S. Appl. No. 17/783,782.

English translation of the Written Opinion of the International Searching Authority issued in PCT application No. PCT/EP2020/075049, dated Nov. 3, 2020, 5 pp.

English translation of the Written Opinion of the International Searching Authority issued in PCT application No. PCT/EP2020/085380, dated Jan. 13, 2021, 6 pp.

English Translation of the Written Opinion of the International Searching Authority issued in PCT Application No. PCT/EP2021/053011, dated Apr. 16, 2021, 5 pp.

English Translation of Written Opinion dated Feb. 17, 2021 issued in PCT Patent Application No. PCT/EP2020/084543.

Examiner: Orignac, Xavier, Search Report issued in French patent application No. 19/14198, dated Jul. 22, 2020, 2 pp.

Unpublished application entitled Angular Filter, U.S. Appl. No. 17/782,558.

Unpublished Application entitled Optical Filter Suitable for Correcting the Electronic Noise of a Sensor, U.S. Appl. No. 17/783,782.

* cited by examiner

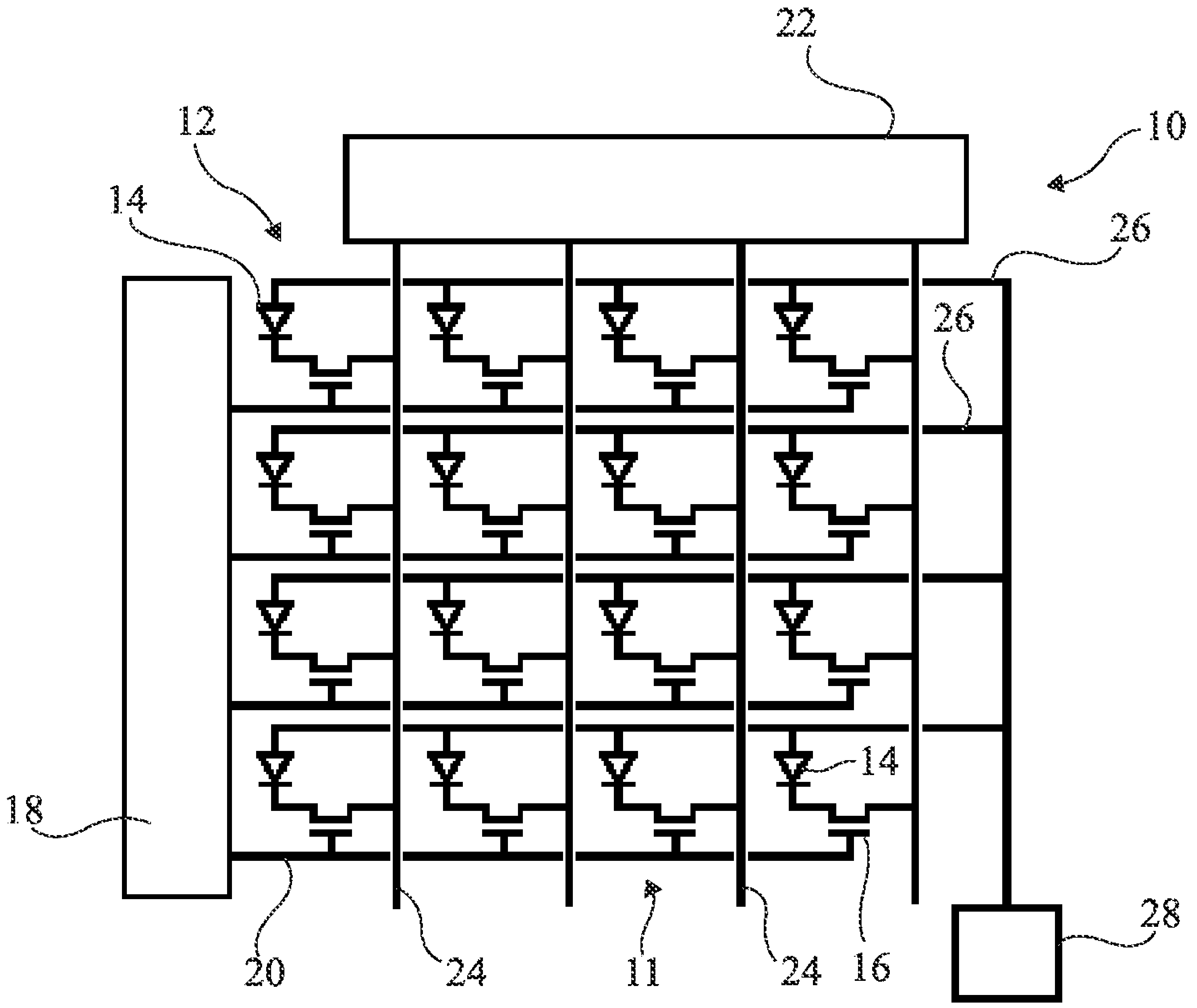

22
12
10
14
26
26
18
14
20
24
11
24
16
28

Fig 1

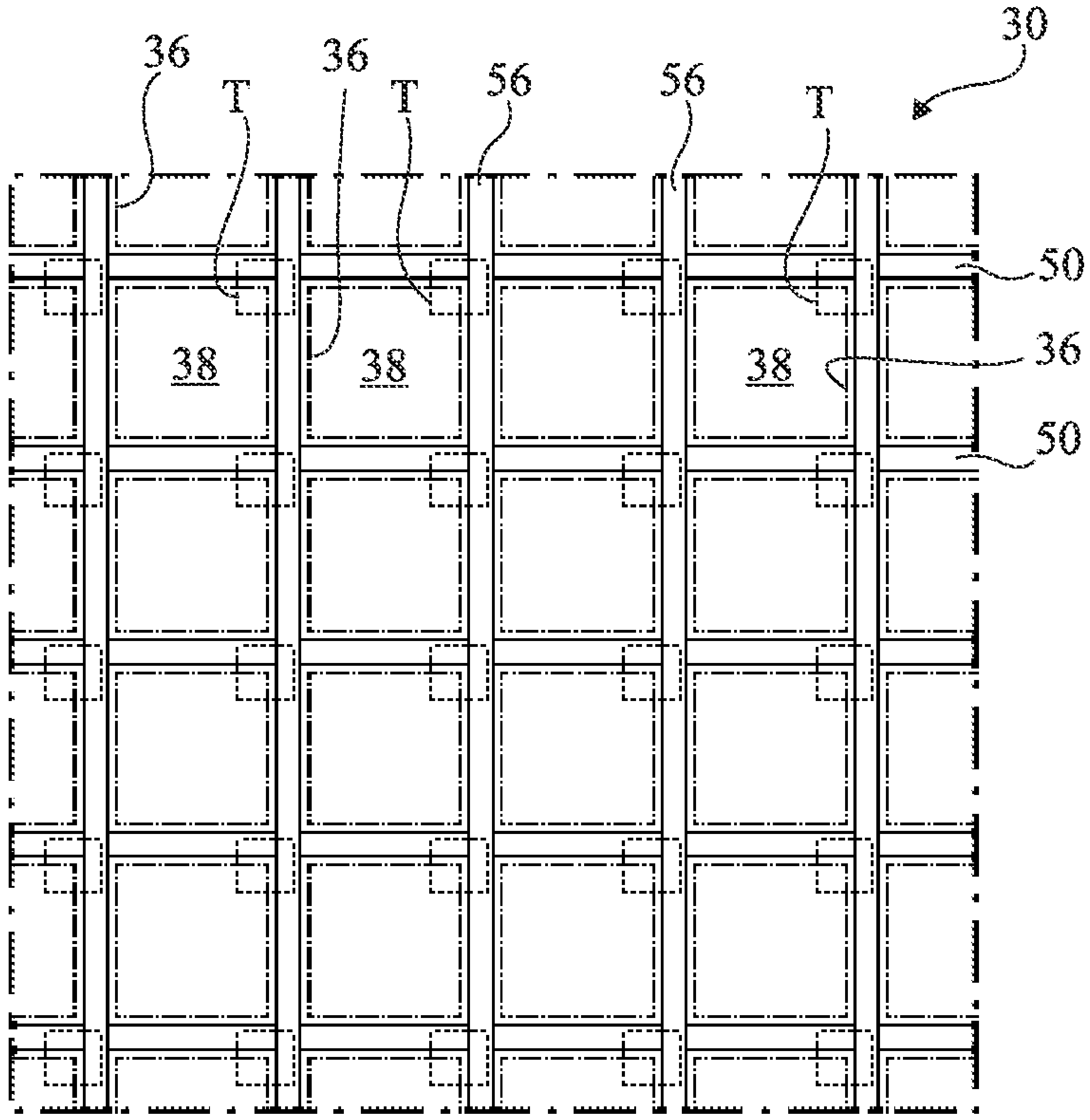

36
T
36
T
56
56
T
30
50
38
38
38
36
50

Fig 2

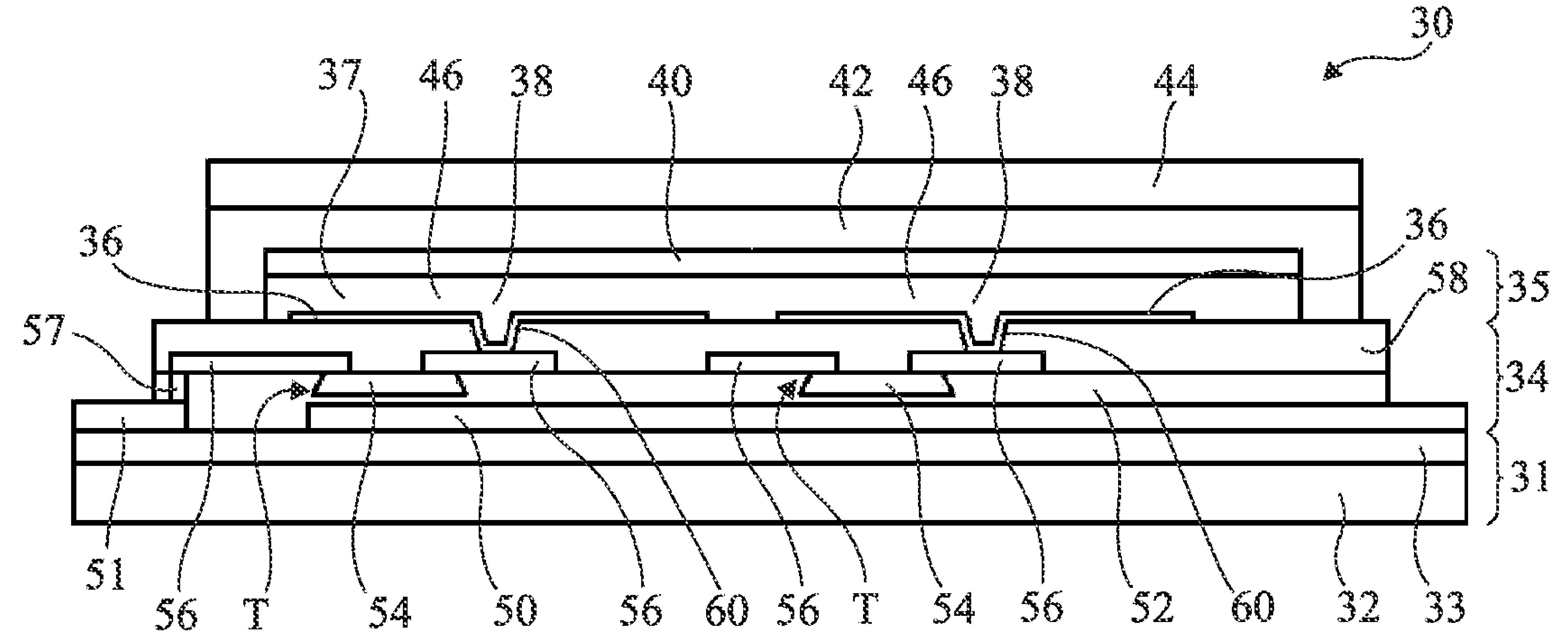


Fig 3

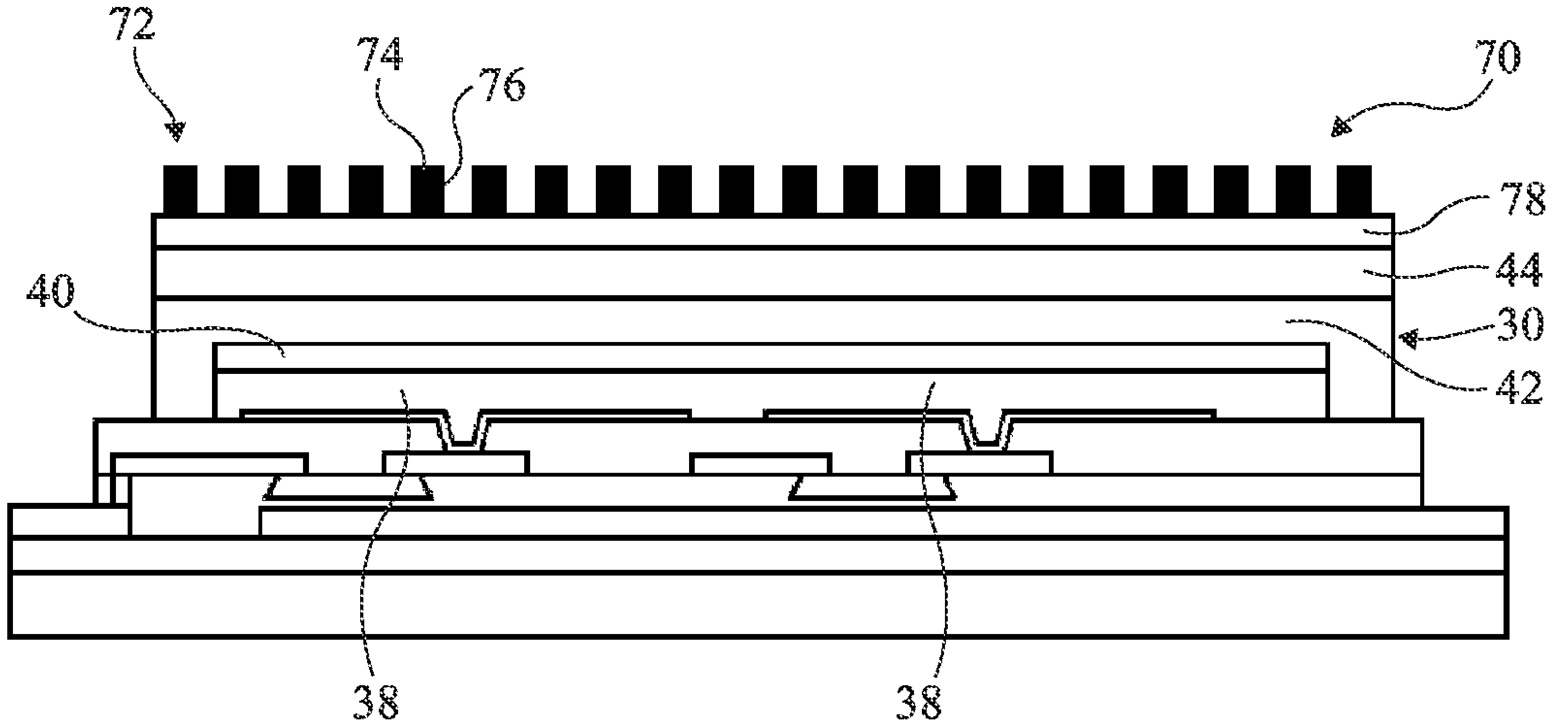


Fig 4

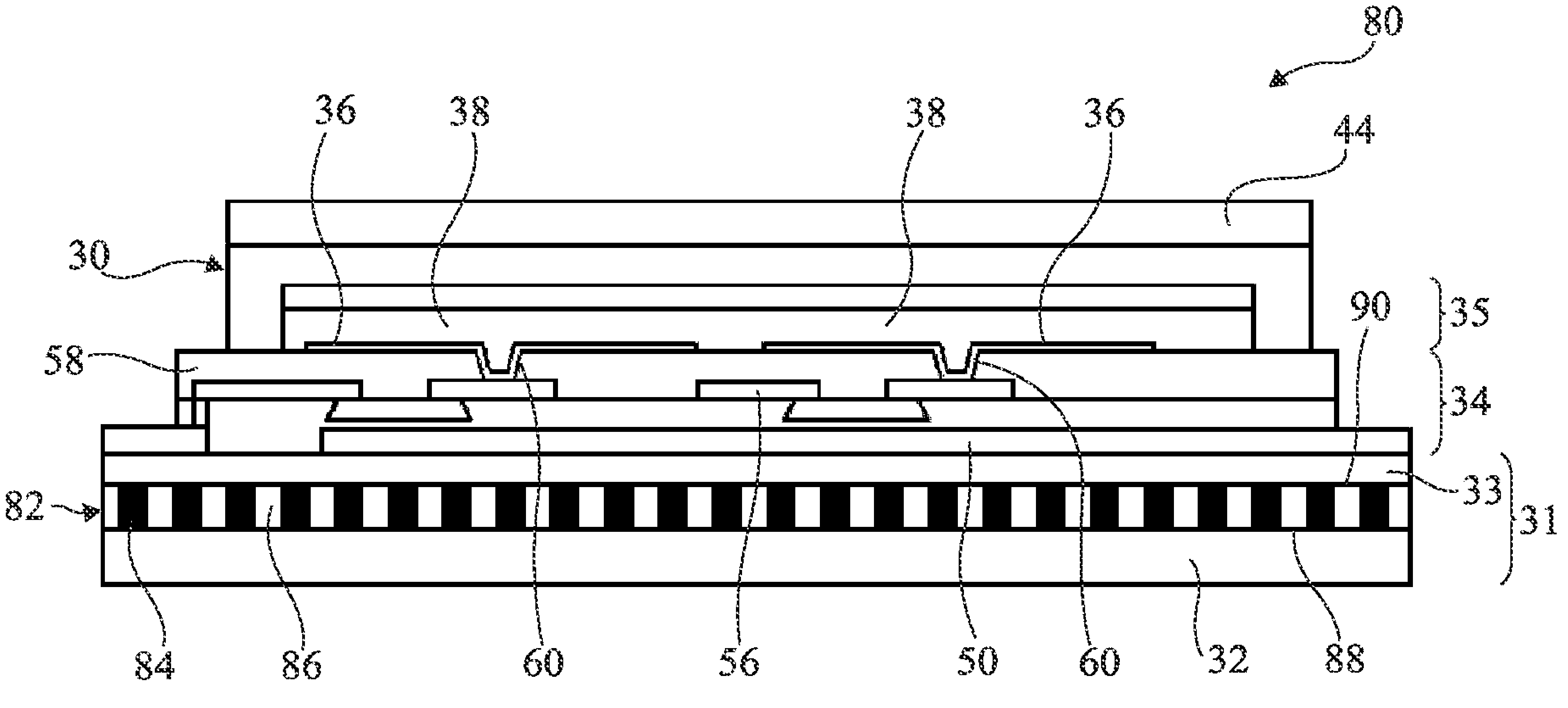


Fig 5

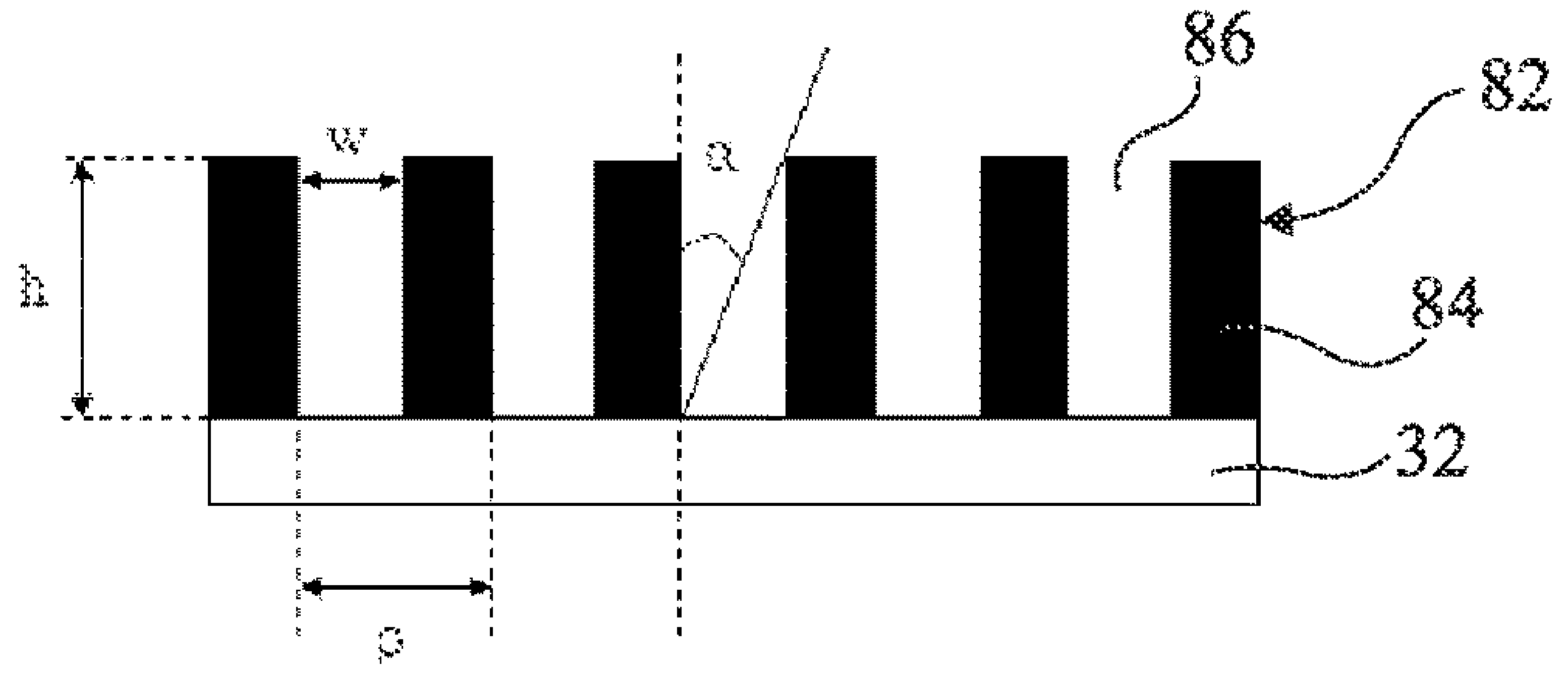


Fig 6

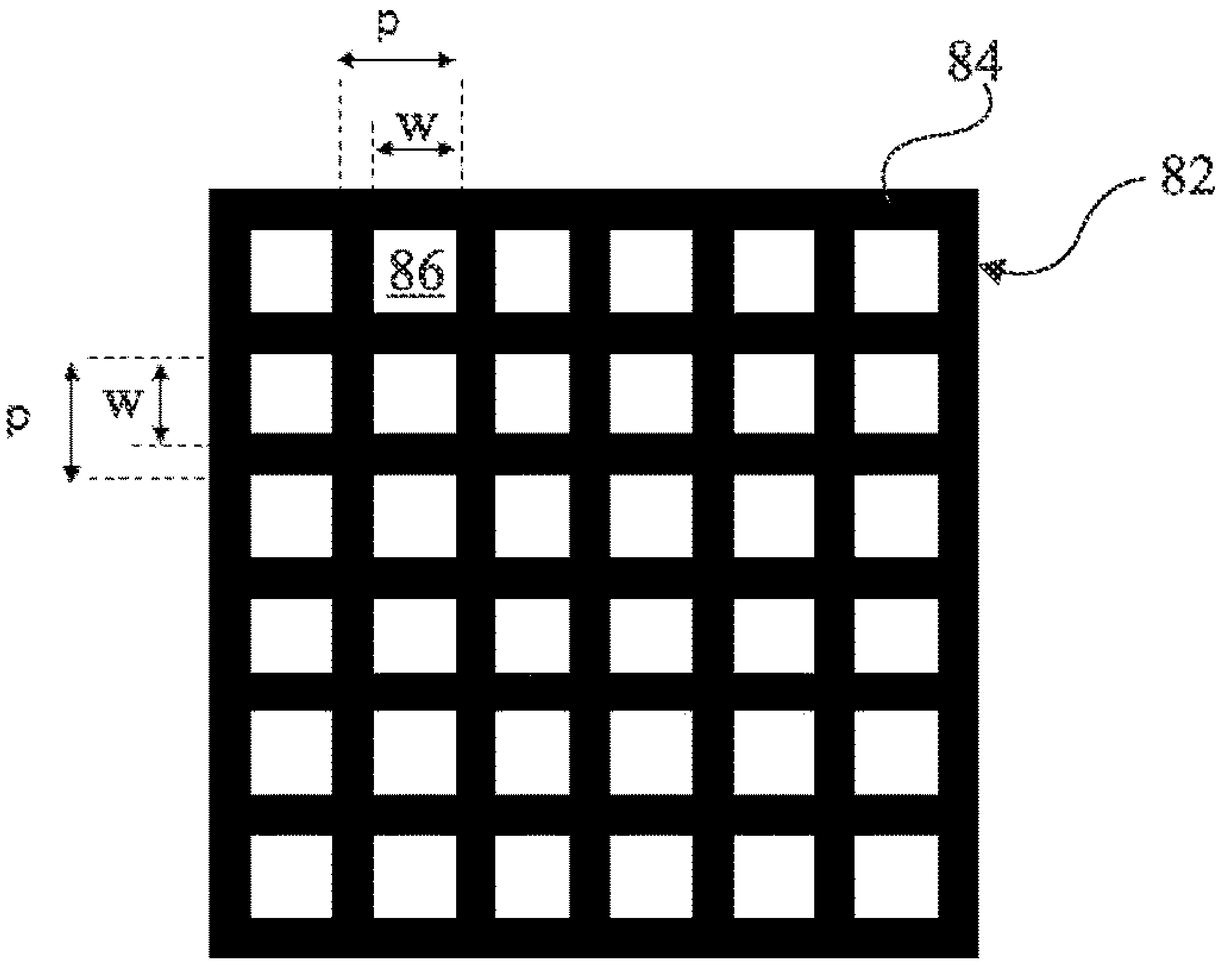


Fig 7

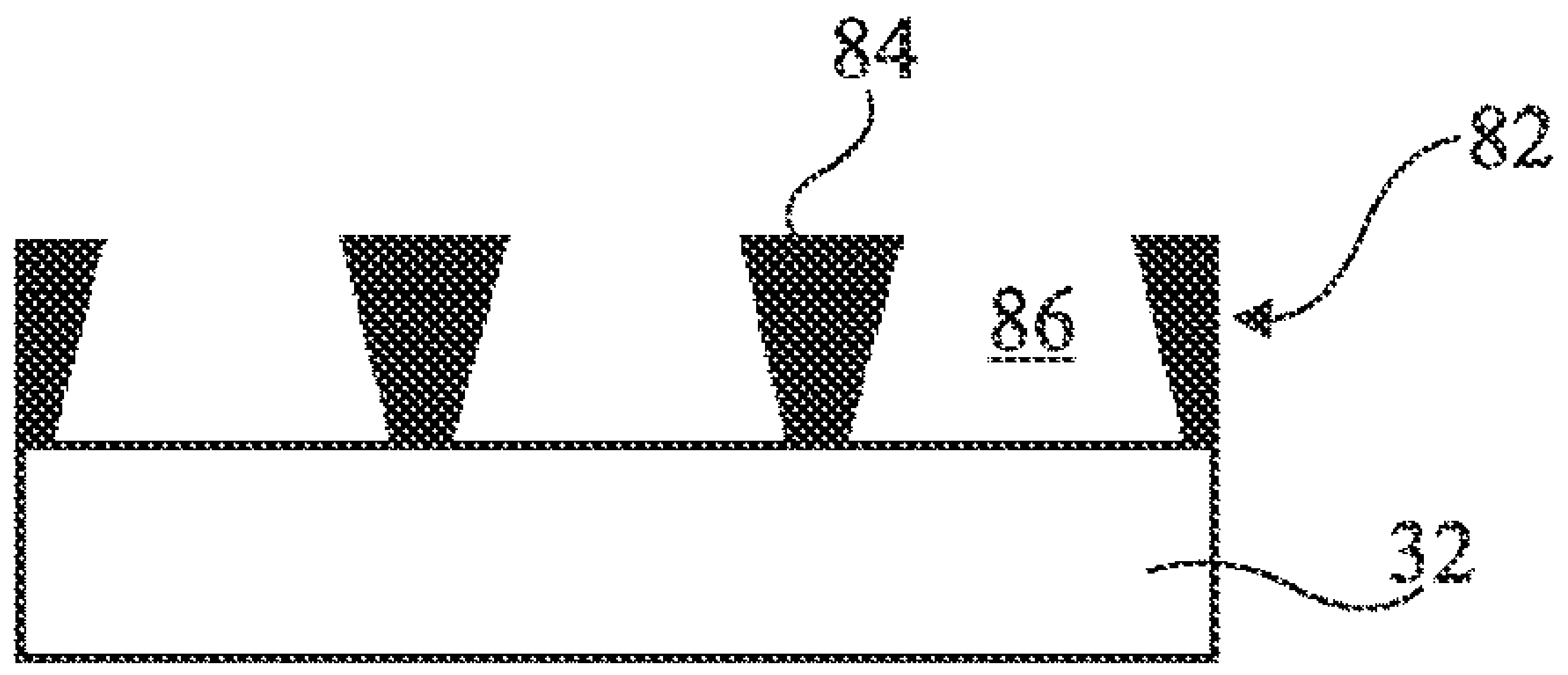


Fig 8

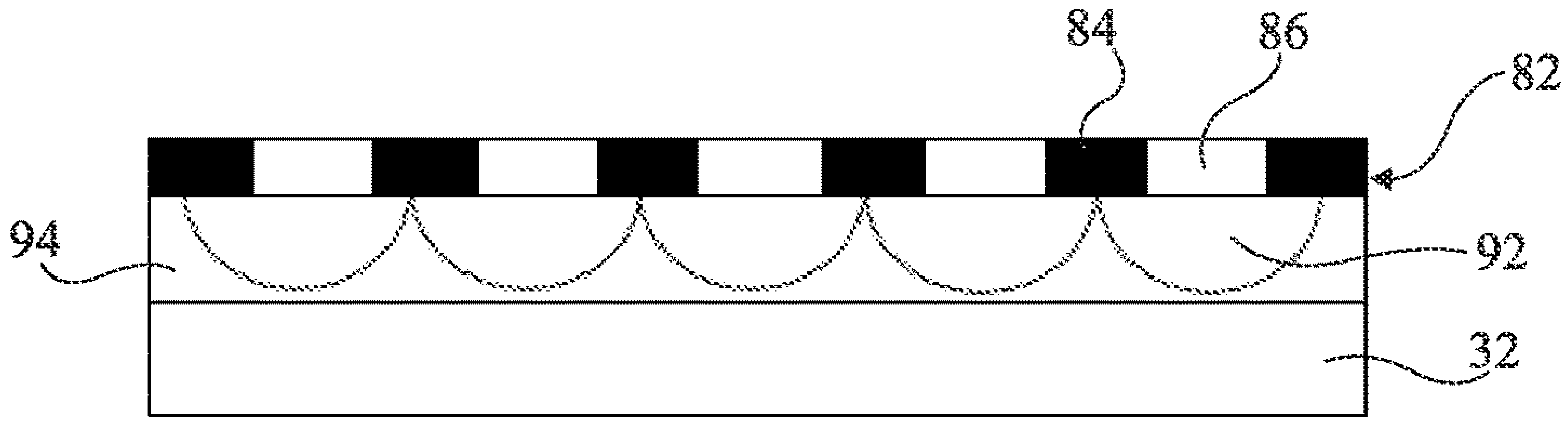


Fig 9

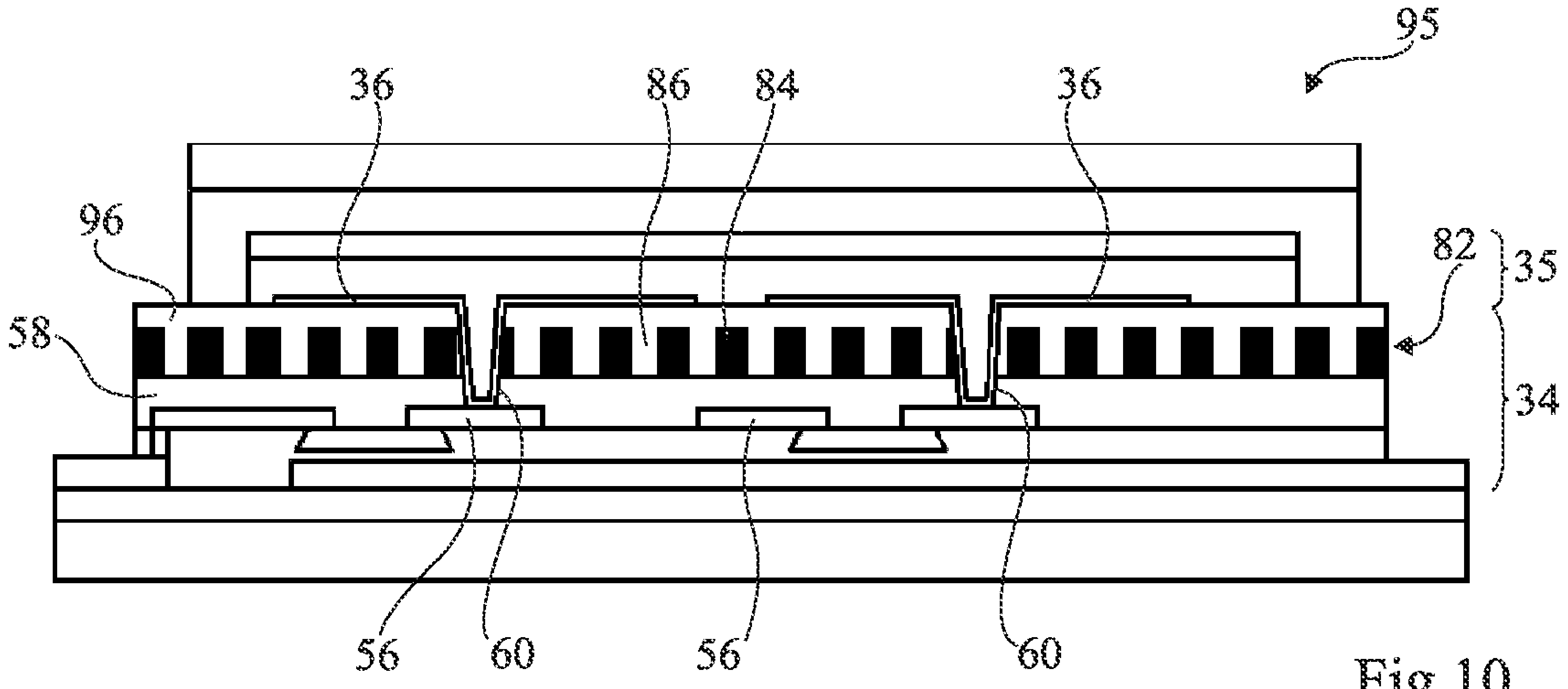


Fig 10

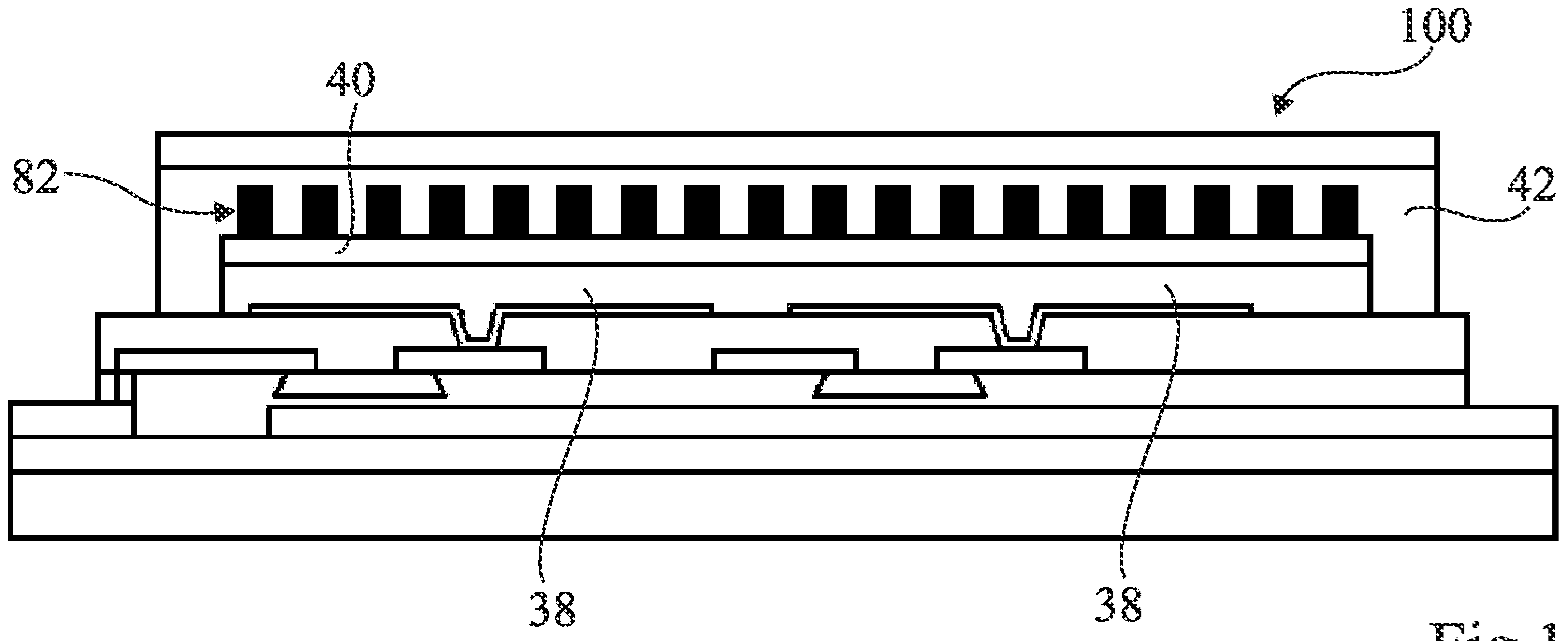


Fig 11

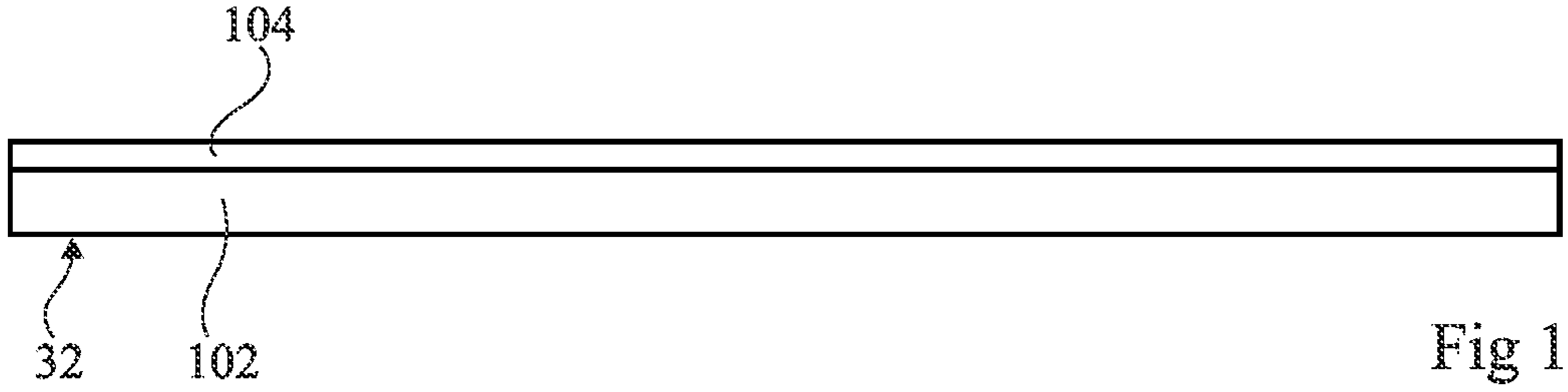


Fig 12

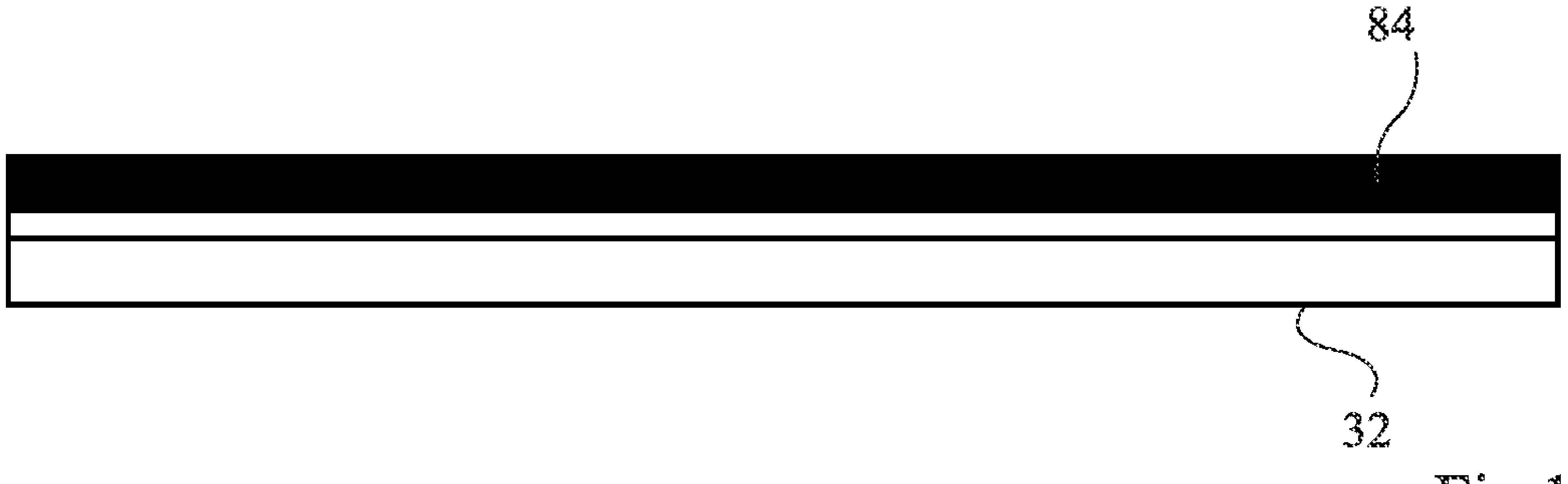


Fig 13

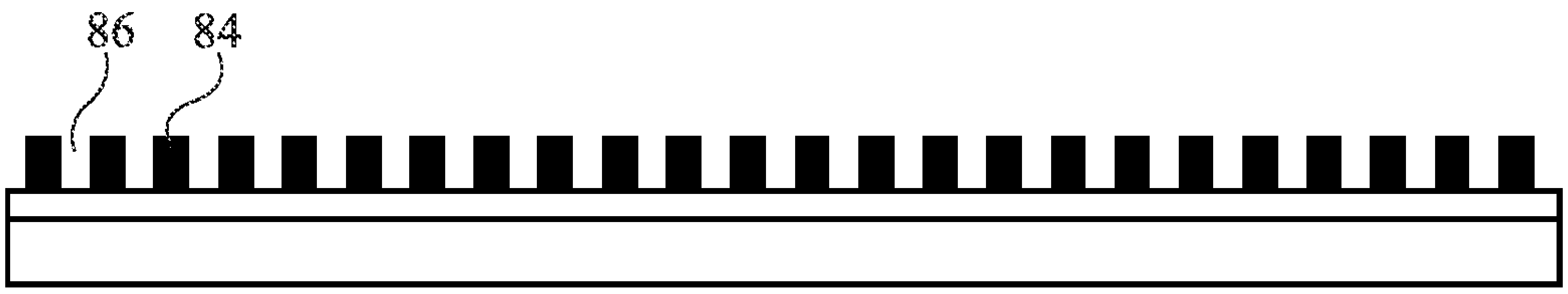


Fig 14

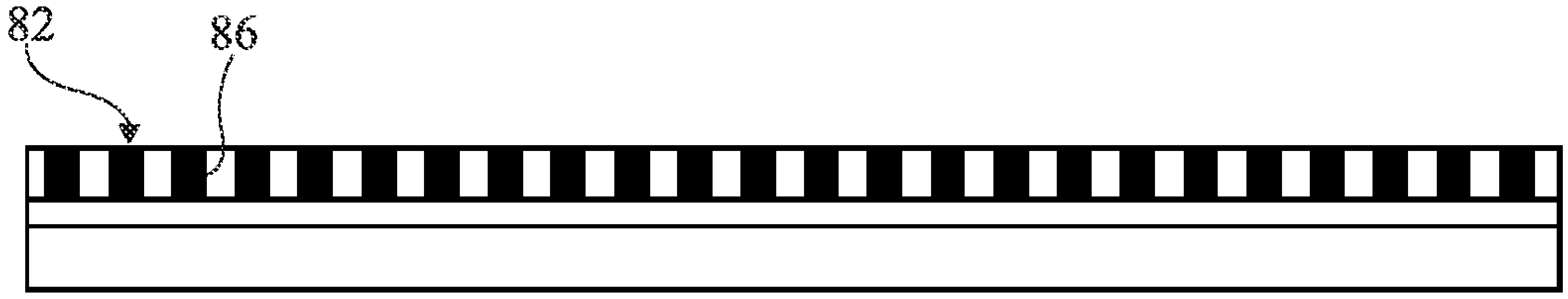


Fig 15

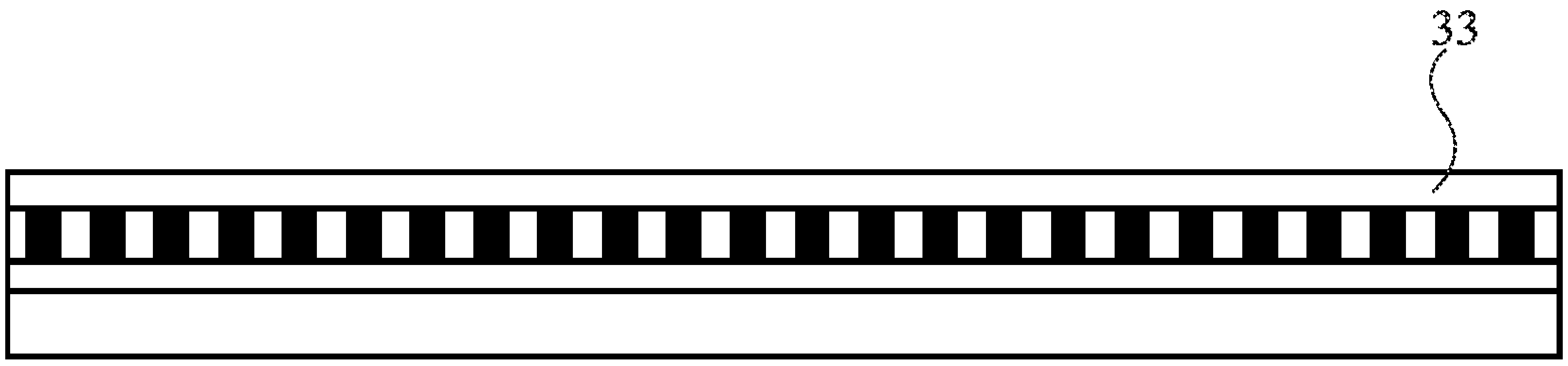


Fig 16

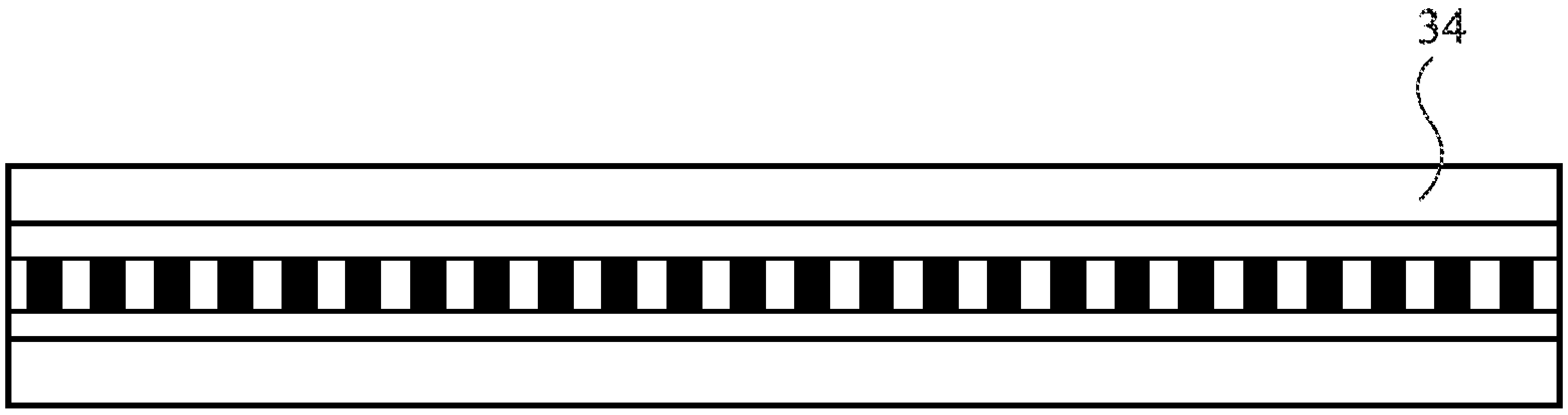


Fig 17

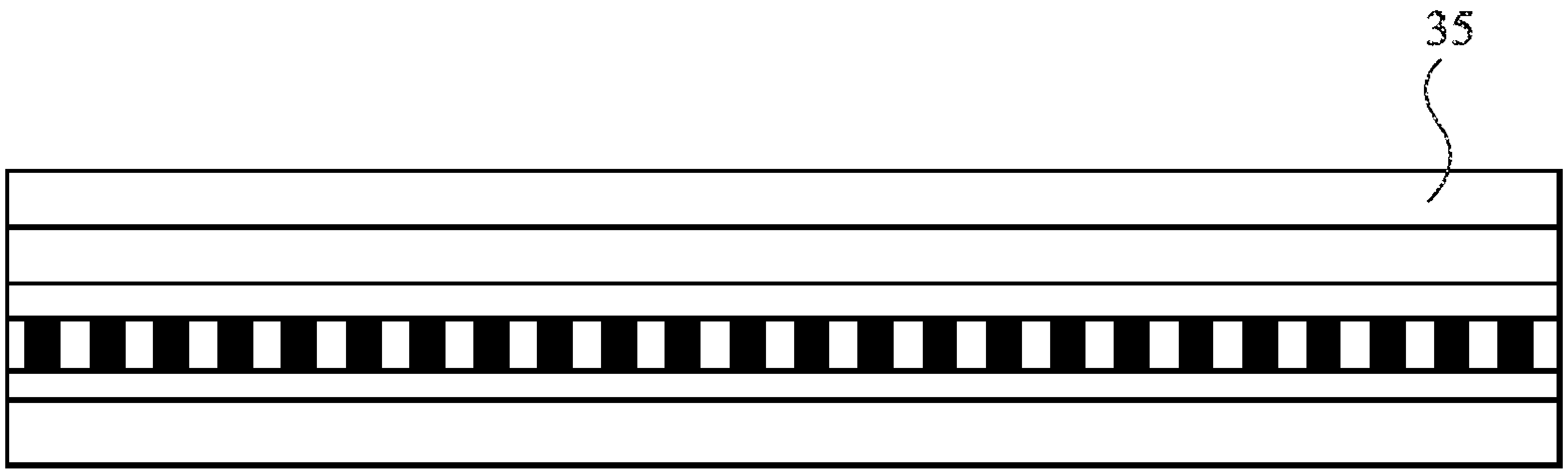


Fig 18

IMAGE SENSOR COMPRISING AN ANGULAR FILTER

CROSS REFERENCE TO RELATED APPLICATIONS

The present patent application claims the priority benefit of French patent application FR19/02965, which is herein incorporated by reference.

FIELD

The present application concerns an image sensor.

BACKGROUND

An image acquisition system comprising an image sensor generally further comprises an optical system, interposed between the sensitive portion of the image sensor and the object to be imaged and which enables to form a sharp image of the object to be imaged on the sensitive portion of the image sensor. A conventional optical system may comprise a succession of fixed or mobile lenses along the optical axis of the image acquisition system.

For certain applications, it is not possible to provide such an optical system, particularly for bulk reasons.

SUMMARY

An object of an embodiment is to increase the sharpness of the image acquired by the image sensor of an image acquisition system in the absence of an optical system forming a sharp image of the object to be imaged on the sensitive portion of the image sensor.

Another object of an embodiment is for the surface area of the sensitive portion of the image sensor to be greater than one square centimeter.

Another object of an embodiment is for the distance between the object to be imaged and the sensitive portion of the image sensor to be shorter than one centimeter.

An embodiment provides an image sensor comprising organic photodetectors and an angular filter less than 20 μm away from the photodetectors.

An embodiment also provides a method of manufacturing an image sensor comprising the forming of organic photodetectors and of an angular filter less than 20 μm away from the photodetectors.

According to an embodiment, the image sensor comprises a surface intended to receive a radiation, said photodetectors being configured to detect said radiation, the angular filter covering the image sensor and being configured to block the rays of said radiation having an incidence relative to a direction orthogonal to the surface greater than a threshold and to give way to rays of said radiation having an incidence relative to a direction orthogonal to the surface smaller than the threshold.

According to an embodiment, the angular filter comprises a layer opaque to said radiation and an array of openings formed in the layer, the openings being filled with air or with a material at least partially transparent to said radiation.

According to an embodiment, for each opening, the ratio of the height of the opening, measured perpendicularly to the surface, to the width of the opening, measured parallel to the surface, varies from 1 to 10.

According to an embodiment, the openings are arranged in rows and in columns, the pitch between adjacent openings of a same row or of a same column varying from 10 μm to 60 μm.

According to an embodiment, the height of each opening, measured along a direction orthogonal to the surface, varies from 1 μm to 1 mm.

According to an embodiment, the width of each opening, measured parallel to the surface, varies from 5 μm to 30 μm.

According to an embodiment, the image sensor comprises a substrate, a first stack of layers comprising thin-film transistors, and a second stack of layers comprising the photodetectors.

According to an embodiment, the angular filter is located in the substrate, between the substrate and the first stack, in the first stack, or between the first stack and the second stack.

According to an embodiment, the photodetectors are coupled to the transistors of the first stack by vias crossing the angular filter.

According to an embodiment, the image sensor comprises an encapsulation film tight to oxygen and to humidity covering the photodetectors and the angular filter covers the photodetectors, on the side of the photodetectors opposite to the first stack, between the photodetectors and the encapsulation film.

According to an embodiment, the image sensor or the method further comprise lenses covering the openings.

According to an embodiment, the photodetectors comprise organic photodiodes.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing features and advantages, as well as others, will be described in detail in the following description of specific embodiments given by way of illustration and not limitation with reference to the accompanying drawings, in which:

FIG. **1** shows an electric diagram of an example of an image sensor;

FIG. **2** is a partial simplified top view of an example of an image sensor of FIG. **1**;

FIG. **3** is a partial simplified cross-section view of the image sensor of FIG. **2**;

FIG. **4** is a partial simplified cross-section view of an example of an image sensor comprising an angular filter;

FIG. **5** is a partial simplified cross-section view of an embodiment of an image sensor comprising an angular filter;

FIG. **6** is a partial simplified cross-section view of an embodiment of the angular filter shown in FIG. **5**;

FIG. **7** is a partial simplified top view of the angular filter shown in FIG. **6**;

FIG. **8** is an enlarged partial simplified cross-section view of another embodiment of an angular filter;

FIG. **9** is an enlarged partial simplified cross-section view of another embodiment of an angular filter;

FIG. **10** is a partial simplified cross-section view of another embodiment of an image sensor comprising an angular filter;

FIG. **11** is a partial simplified cross-section view of another embodiment of an image sensor comprising an angular filter;

FIG. **12** is a partial simplified cross-section view illustrating a step of an embodiment of a method of manufacturing the image sensor shown in FIG. **5**;

FIG. **13** illustrates another step of the method;

FIG. **14** illustrates another step of the method;

FIG. **15** illustrates another step of the method;

FIG. **16** illustrates another step of the method;

FIG. **17** illustrates another step of the method; and

FIG. **18** illustrates another step of the method.

DESCRIPTION OF THE EMBODIMENTS

Like features have been designated by like references in the various figures. In particular, the structural and/or functional features that are common among the various embodiments may have the same references and may dispose identical structural, dimensional and material properties. For the sake of clarity, only the elements that are useful for an understanding of the embodiments described herein have been illustrated and described in detail. In particular, the operation of an image sensor has not been detailed, the described embodiments being compatible with usual image sensors.

In the following disclosure, unless indicated otherwise, when reference is made to absolute positional qualifiers, such as the terms "front", "back", "top", "bottom", "left", "right", etc., or to relative positional qualifiers, such as the terms "above", "below", "higher", "lower", etc., or to qualifiers of orientation, such as "horizontal", "vertical", etc., reference is made to the orientation shown in the figures, or to an image sensor as orientated during normal use. Unless specified otherwise, the expressions "around", "approximately", "substantially" and "in the order of" signify within 10%, and preferably within 5%. Unless specified otherwise, the expressions "around", "approximately", "substantially" and "in the order of" signify within 10%, and preferably within 5%.

The expression active region of a photodetector designates the region from which most of the electromagnetic radiation received by the photodetector is captured. In the following description, an optoelectronic component is called organic when the active region of the optoelectronic component is mainly, preferably totally, made of at least one organic material or of a mixture of organic materials.

The transmittance of a layer corresponds to the ratio of the intensity of the radiation coming out of the layer to the intensity of the radiation entering the layer, the rays of the incoming radiation being perpendicular to the layer. In the following description, a layer or a film is called opaque to a radiation when the transmittance of the radiation through the layer or the film is smaller than 10%. In the following description, a layer or a film is called transparent to a radiation when the transmittance of the radiation through the layer or the film is greater than 10%.

The refraction index of a material corresponds to the refraction index of the material for the wavelength range of the radiation captured by the image sensor. Unless specified otherwise, the refraction index is considered as substantially constant over the wavelength range of the useful radiation, for example, equal to the average of the refraction index over the wavelength range of the radiation captured by the image sensor.

In the following description, "visible light" designates an electromagnetic radiation having a wavelength in the range from 400 nm to 700 nm and "infrared radiation" designates an electromagnetic radiation having a wavelength in the range from 700 nm to 1 mm. In infrared radiation, one can particularly distinguish near infrared radiation having a wavelength in the range from 700 nm to 1.4 μm.

FIG. **1** partially and schematically shows an image sensor **10**. Image sensor **10** comprises an array **11** of detection elements **12**, called detection array hereafter. Detection elements **12** may be arranged in rows and in columns. Each detection element **12** comprises a photodetector **14**, for example, a photodiode, and a selection element **16**, for example, a transistor having its source or drain coupled to a first electrode of photodiode **14**, for example, the cathode. Image sensor **10** comprises a selection circuit **18** comprising, for each row, a conductive track **20** coupled to the gates of selection transistors **16**. Image sensor **10** further comprises a readout circuit **22** comprising, for example, for each column, a conductive track **24** coupled to the source or to the drain of column selection transistors **16**. Further, the second electrodes of photodiodes **14**, for example, the anodes, may coupled by conductive tracks **26** to a source **28** of a reference potential.

FIGS. **2** and **3** respectively are a top view and a lateral cross-section view, partial and simplified, of an example of a detection array **30** having an equivalent electric diagram that may correspond to the detection array **11** shown in FIG. **1**.

Detection array **30** comprises, from bottom to top in FIG. **3**:

a support **31** that may have a monolayer or multilayer structure and which, in FIG. **3**, comprises a substrate **32** covered with an intermediate layer **33**;

a stack **34** having thin-film transistors T formed therein, only two transistors T being shown in FIG. **3**;

a stack **35** having photodetectors **38** formed therein, for example, organic photodiodes, also called OPD, stack **35** comprising lower electrodes **36**, each electrode **36** being coupled to one of transistors T, a layer **37** in contact with electrodes **36** and having the active regions of photodiodes **38** formed therein, and an upper electrode **40** in contact with layer **37**, only two photodiodes **38** and two electrodes **36** being shown in FIG. **3**;

a layer of an adhesive material **42**; and

a coating **44**.

Each photodiode **38** comprises an active region **46** corresponding to the portion of layer **37** interposed between the electrode **36** associated with photodiode **38** and electrode **40**. As a variant, each organic photodiode **38** may comprises a first interface layer in contact with one of electrodes **36**, the active region **46** in contact with the first interface layer, and a second interface layer in contact with active region **46**, electrode **40** being in contact with the second interface layer.

According to the present example, stack **34** comprises:

electrically-conductive tracks **50**, **51** resting on support **31**, tracks **50** forming the gate conductors of transistors T, which corresponds to the tracks **20** of the equivalent electric diagram of FIG. **1**, and tracks **51** being coupled to the drains or to the sources of transistors T;

a layer **52** of a dielectric material covering tracks **50**, **51** and support **31** between tracks **50**, **51** and forming the gate insulators of transistors T;

active regions **54** resting on dielectric layer **52** opposite gate conductors **50**;

electrically-conductive tracks **56** extending on dielectric layer **52** forming the drain and source contacts of transistors T, and particularly corresponding to the tracks **24** of the equivalent electric diagram of FIG. **1**, some of tracks **56** coupling active regions **54** to electrodes **36** and some of tracks **56** being electrically coupled to tracks **51** via electrically-conductive vias **57** extending through layer **52**; and

a layer **58** of a dielectric material covering active regions **54** and electrically-conductive tracks **56**, electrodes **36** resting on layer **58** and being connected to some of conductive tracks **56** by conductive vias **60** crossing insulating layer **58** and electrode **40** being connected to some of conductive tracks **51** by conductive vias, not shown in FIGS. **2** and **3**, crossing insulating layers **58** and **52**.

In FIG. **3**, transistors T are shown with a so-called inverse staggered structure. As a variant, transistors T may be of staggered type.

When at least one interface layer is present in contact with active region **46**, this interface layer may correspond to an electron injection layer or to a hole injection layer. The work function of each interface layer is capable of blocking, collecting, or injecting holes and/or electrons according to whether the interface layer plays the role of a cathode or of an anode. More particularly, when the interface layer plays the role of an anode, it corresponds to a hole injection and electron blocking layer. The work function of the interface layer is then greater than or equal to 4.5 eV, preferably greater than or equal to 5 eV. When the interface layer plays the role of a cathode, it corresponds to an electron injection and hole blocking layer. The work function of the interface layer is then smaller than or equal to 4.5 eV, preferably smaller than or equal to 4.2 eV. In the present embodiment, electrode **36** or **40** advantageously directly plays the role of an electron injection layer or of a hole injection layer for photodiode **38**, and it is not necessary to provide, for photodiode **38**, an interface layer in contact with active region **46** and playing the role of an electron injection layer or of a hole injection layer.

FIG. **4** is a lateral cross-section view of an example of an image sensor **70**. Image sensor **70** comprises the detection array **30** shown in FIGS. **2** and **3** and further comprises an angular filter **72** corresponding to an opaque film **74** crossed by openings **76**. Opaque film **74** is attached to coating **44** by lamination by using a layer of an adhesive material **78**. Angular filter **72** is adapted to filtering the light rays according to their incidence to improve the sharpness of the images acquired by the image sensor. The angle of incidence beyond which the incident rays are blocked particularly depends on the ratio of the height to the width of openings **76**.

The thickness of upper electrode **40** may be in the order of 500 nm. The thicknesses of the layers of adhesive material **42**, **78** may be in the order of 25 μm. The thickness of coating **44** may be in the order of 50 μm. A disadvantage of the image sensor **70** shown in FIG. **4** then is that the distance between angular filter **72** and photodiodes **38** is generally greater than 100 μm. This may impose the use of a high height-to-width ratio for the openings **76** of angular filter **72** and complicate the manufacturing of angular filter **72**. Further, the use of a high height-to-width ratio causes a decrease in the transmittance of angular filter **72**, which may not be desirable. For certain applications, it is desirable to accurately place openings **76** relative to photodiodes **38**. A disadvantage of image sensor **70** then is that the alignment of angular filter **72** relative to photodiodes **38** requires the implementation of additional assembly techniques, which increases the manufacturing costs of the image sensor.

FIG. **5** is a lateral cross-section view of an embodiment of an image sensor **80**. Image sensor **80** comprises the detection array **30** shown in FIGS. **2** and **3**, with the difference than an angular filter **82** is arranged between substrate **32** and stack **34**. In the present embodiment, angular filter **82** is arranged between substrate **32** and intermediate layer **33**. Image sensor **80** is intended to be illuminated on the side of substrate **32**. As shown in FIG. **2**, the conductive tracks **50** coupled to the gates of transistors T extend between the columns of photodiodes **38**, and the conductive tracks **56** coupled to the sources of transistors T extend between the rows of photodiodes **38**. Thereby, tracks **50**, **56** may be non-transparent to the radiation captured by photodiodes **38** since they do not cover photodiodes **38**.

Angular filter **82** corresponds to a layer **84**, opaque to the radiation captured by photodetectors **38**, and crossed by openings **86**. Angular filter **82** comprises a lower surface **88** facing the side of substrate **32** and an upper surface **90** facing the side of photodiodes **38**. Surfaces **88**, **90** are preferably substantially planar. In the present embodiment, the distance between the upper surface **90** of angular filter **82** and photodiodes **38** is shorter than 20 μm, preferably shorter than 10 μm, more preferably shorter than 6 μm.

Angular filter **82** is capable of filtering the incident rays according to the incidence of the rays relative to the lower surface **88** of angular filter **82**, particularly so that each photodetector **38** only receives rays having an incidence relative to an axis perpendicular to the lower surface **88** of angular filter **82** smaller than a maximum angle of incidence smaller than 45°, preferably smaller than 30°, more preferably smaller than 20°, more preferably still smaller than 10°. Angular filter **82** is capable of blocking the incident rays of the incident radiation having an incidence relative to an axis perpendicular to lower surface **88** of angular filter **82** smaller than the maximum angle of incidence.

Detection array **30** may further comprise a polarizing filter, arranged, for example, over coating **44** or over substrate **32** according to the illumination of the image sensor. Detection array **30** may further comprise color filters opposite photodetectors **38** to obtain a wavelength selection of the radiation reaching photodetectors **38**.

FIGS. **6** and **7** respectively are a cross-section view and a top view, partial and simplified, of an embodiment of angular filter **82**.

Call "h" the height of openings **86** measured from substrate **32**. Layer **84** is opaque to the radiation detected by photodetectors **38**, for example, absorbing and/or reflective with respect to the radiation detected by photodetectors **38**. According to an embodiment, layer **84** is absorbing in the visible range and/or near infrared and/or infrared.

In FIG. **7**, openings **86** are shown with a square cross-section. Generally, the cross-section of openings **86** in the top view may be circular, oval, or polygonal, for example, triangular, square, or rectangular.

According to an embodiment, openings **86** are arranged in rows and in columns. Openings **86** may have substantially the same dimensions. Call "w" the width of an opening **86** measured along the row or column direction. According to an embodiment, openings **86** are regularly arranged in rows and in columns. Call "p" the repetition pitch of openings **86**, that is, the distance in top view between centers of two successive openings **86** of a row or of a column.

The angular filter **82** shown in FIGS. **6** and **7** only gives way to the rays of the incident radiation having an incidence relative to substrate **32** smaller than a maximum angle of incidence α, which is defined by the following relation (1):

[Math 1]

$$\tan\alpha = w/h \qquad (1)$$

The smaller ratio w/h, the smaller the maximum angle of incidence α. The transmittance for a zero incidence of angular filter **82** is proportional to the ratio of the transparent surface area in top view to the absorbing surface area of angular filter **82**. For applications at a low light level, it is desirable for the transmittance to be the highest possible to increase the quantity of light collected by image sensor **80**. For applications at a high light level, the transmittance may be decreased to avoid blooming image sensor **80**.

According to an embodiment, photodetectors **38** may be distributed in rows and in columns. According to an embodiment, the pitch p of openings **86** is smaller than the pitch of the photodetectors **38** of image sensor **80**. In this case, a plurality of openings **86** may be located opposite a photodetector **38**, as schematically shown in FIG. **5**. According to another embodiment, the pitch p of openings **86** is identical to the pitch of the photodetectors **38** of image sensor **80**. Angular filter **82** is then preferably aligned with image sensor **80** so that each opening **86** is opposite a photodetector **38**. According to an embodiment, the pitch p of openings **86** is larger than the pitch of the photodetectors **38** of image sensor **80**. In this case, a plurality of photodetectors **38** may be located opposite an opening **86**.

The h/w ratio may be in the range from 1 to 10. Pitch p may be in the range from 10 μm to 60 μm, for example, approximately 15 μm. Height h may be in the range from 1 μm to 1 mm, preferably from 20 μm to 100 μm. Width w may be in the range from 5 μm to 30 μm, for example, approximately 10 μm.

FIG. **8** is a partial simplified cross-section view of a variant of the embodiment shown in FIG. **6**, where the cross-section of openings **86** is not constant, the cross-section decreasing as the distance to substrate **32** increases. As a variant, the cross-section may increase as the distance to substrate **32** increases, successively comprise a phase of decrease followed by a phase of enlargement as the distance to substrate **32** increases, etc.

FIG. **9** is a partial simplified cross-section view of another embodiment of angular filter **82**. Angular filter **82** comprises the structure shown in FIGS. **6** and **7** and further comprises, for each opening **86**, a microlens **92** resting on layer **84** and covering opening **86**. A bonding layer **94** is arranged between microlenses **92** and substrate **32**.

Each microlens **92** advantageously enables to increase the collection of rays of the incident radiation having an incidence smaller than a desired maximum angle of incidence but which would be blocked by the walls of openings **86** in the absence of microlens **92**. Such an embodiment is particularly adapted to applications where the light level is low. The filling material of openings **86** may be the same as the material forming microlenses **92**. The microlenses may be converging lenses each having a focal distance f in the range from 1 μm to 100 μm, preferably from 1 μm to 50 μm.

The pitch of microlenses **92** may be the same as the pitch of photodetectors **38** or smaller. In the presence of microlenses **92**, the openings **86** of angular filter **82** essentially act as an optical micro-diaphragm between microlenses **92** and photodetectors **38** so that there is less constraint on the aspect ratio w/h of openings **86** as compared with the case where microlenses **92** are not present. The maximum angle of incidence is determined by the width w of openings **86** and the curvature of microlenses **92**.

As a variant, each microlens may be replaced with another type of micrometer-range optical element, particularly a micrometer-range Fresnel lens, a micrometer-range index gradient lens, or a micrometer-range diffraction grating.

FIG. **10** is a lateral cross-section view of an embodiment of an image sensor **95**. Image sensor **95** comprises all the elements of the image sensor **80** shown in FIG. **5**, with the difference that angular filter **82** is located in stack **34**. In the present embodiment, angular filter **82** is located in an insulating layer **96** covering layer **58**. The height h of openings **86** may be equal to or smaller than the thickness of insulating layer **96**. Insulating layer **96** may fill openings **86**. Vias **60**, which couple electrodes **36** to conductive tracks **56**, thus further cross angular filter **82** and insulating layer **96**. Image sensor **95** is intended to be illuminated on the side of substrate **32**.

FIG. **11** is a lateral view of an embodiment of an image sensor **100**. Image sensor **100** comprises all the elements of the image sensor **80** shown in FIG. **5**, with the difference that angular filter **82** is located on electrode **40**, on the side of electrode **40** opposite to photodetectors **38**. Openings **86** may be filled with the adhesive material of adhesive layer **42**. Image sensor **100** is intended to be illuminated on the side of coating **44**.

Substrate **32** is made of a material at least partially transparent to the radiation captured by photodetectors **38**. Substrate **32** may be a rigid substrate or a flexible substrate. Substrate **32** may have a monolayer structure or correspond to a stack of at least two layers. An example of a rigid substrate comprises a silicon, germanium, or glass substrate. Preferably, substrate **32** is a flexible film. An example of flexible substrate comprises a film of PEN (polyethylene naphthalate), PET (polyethylene terephthalate), PI (polyimide), TAC (cellulose triacetate), COP (cycloolefin copolymer), or PEEK (polyetheretherketone). Substrate **32** may comprise an inorganic layer, for example, made of glass, covered with an organic layer, for example, made of PEN, PET, PI, TAC, COP. The thickness of substrate **32** may be in the range from 5 μm to 1,000 μm. According to an embodiment, substrate **32** may have a thickness in the range from 10 μm to 500 μm, preferably from 20 μm to 300 μm, particularly in the order of 75 μm, and may have a flexible behavior, that is, substrate **32** may, under the action of an external force, deform, and particularly bend, without breaking or tearing.

Intermediate layer **33** may be a layer substantially tight to oxygen and to humidity to protect the organic layers of detection area **30**. It may be a layer or layers deposited by atomic layer deposition (ALD), for example, an Al_2O_3 layer, layers deposited by physical vapor deposition (PVD) or by plasma-enhanced chemical vapor deposition (PECVD), for example, made of SiN or of SiO_2. Intermediate layer **33** may have a monolayer structure or correspond to a stack of at least two layers, comprising, for example, organic layers and inorganic layers.

Conductive tracks **50**, **51**, **56**, electrode **40** (when the image sensor is intended to be illuminated on the side of substrate **32**), and electrode **36** and via **60** (when the image sensor is intended to be illuminated on the side of coating **44**) may be made of a metallic material, for example, silver (Ag), aluminum (Al), gold (Au), copper (Cu), nickel (Ni), titanium (Ti), chromium (Cr), and molybdenum (Mo). Conductive tracks **50**, **51**, **56**, electrode **40** (when the image sensor is intended to be illuminated on the side of substrate **32**), and electrode **36** and via **60** (when the image sensor is intended to be illuminated on the side of coating **44**) may have a monolayer or multilayer structure.

Each insulating layer **52**, **58**, **96** of stack **34** may be made of an inorganic material, for example, of silicon oxide (SiO_2) or of silicon nitride (SiN), or an insulating organic layer, for example, made of organic resin.

According to an embodiment, the material forming electrodes **36**, **40** is selected from the group comprising:

transparent conductive oxides (TCO), particularly indium tin oxide (ITO), aluminum zinc oxides (AZO), gallium zinc oxides (GZO), tungsten oxide (WO_3), nickel oxide (NiO), vanadium oxide (V_2O_5), molybdenum oxide

- (MoO_3), ITO/Ag/ITO alloys, ITO/Mo/ITO alloys, AZO/Ag/AZO alloys, or ZnO/Ag/ZnO alloys;
- metals or a metal alloys, for example, silver (Ag), gold (Au), lead (Pb), palladium (Pd), copper (Cu), nickel (Ni), tungsten (W), molybdenum (Mo), aluminum (Al), or chromium (Cr), or an alloy of magnesium and silver (MgAg);
- carbon, silver, and/or copper nanowires;
- graphene;
- conductive polymers, particularly the PEDOT:PSS polymer, which is a mixture of poly(3,4)-ethylenedioxythiophene and of sodium polystyrene sulfonate, or a polyaniline; and
- mixtures of at least two of these materials.

When detection array **30** is exposed to a light radiation which reaches photodiodes **38** through coating **44**, electrode **40** and coating **44** are at least partly transparent to the electromagnetic radiation captured by photodiodes **38**. Electrode **40** is for example made of TCO or of a doped polymer, for example, of PEDOT:PSS. Electrodes **36** and substrate **32** may then be opaque to the electromagnetic radiation captured by photodiodes **38**. When the radiation reaches photodiodes **38** through substrate **32**, electrodes **36** and substrate **32** are made of a material at least partly transparent to the electromagnetic radiation captured by photodiodes **38**. Electrodes **36** are for example made of TCO. Electrode **40** may then be opaque to the electromagnetic radiation captured by photodiodes **38**.

When the image sensor is illuminated on the side of coating **44**, adhesive material layer **42** is transparent or partially transparent to visible light. Layer **42** of adhesive material is preferably substantially air- and water-tight. The material forming layer **42** of adhesive material is selected from the group comprising a polyepoxide or a polyacrylate. Among polyepoxides, the material forming layer **42** of adhesive material may be selected from the group comprising bisphenol A epoxy resins, particularly the bisphenol A diglycidyl ether (DGEBA) and the bisphenol A and tetrabromobisphenol A diglycidyl ethers, bisphenol F epoxy resins, novolac epoxy resins, particularly epoxy-phenol-novolacs (EPN) and epoxy-cresol-novolacs (EON), aliphatic epoxy resins, particularly epoxy resins with glycidil groups and cycloaliphatic epoxides, glycidyl amine epoxy resins, particularly the methylene dianiline glycidyl ethers (TGMDA), and a mixture of at least two of these compounds. Among polyacrylates, the material forming layer **42** of adhesive material may be made of monomers comprising acrylic acids, methyl methacrylate, acrylonitrile, methacrylates, methyl acrylate, ethyl acrylate, 2-chloroethyl vinyl ether, 2-ethylhexyl acrylate, hydroxyethyl methacrylate, butyl acrylate, butyl methacrylate, trimethylol propane triacrylate (TMPTA), or derivatives of these products. When layer **42** of adhesive material comprises at least one polyepoxide or one polyacrylate, the thickness of the layer of adhesive material **42** is in the range from 1 μm to 50 μm, preferably from 5 μm to 40 μm, particularly in the order of 15 μm.

Coating **44** is a flexible film. An example of flexible film comprises a film of PEN (polyethylene naphthalate), PET (polyethylene terephthalate), PI (polyimide), TAC (cellulose triacetate), COP (cycloolefin copolymer), or PEEK (polyetheretherketone). The thickness of coating **44** may be in the range from 5 μm to 1,000 μm. Coating **44** may comprise at least one layer substantially tight to oxygen and to humidity protect the organic layers of detection array **30**. Coating **44** may comprise at least one SiN layer, for example, deposited by PECVD and/or one aluminum oxide layer (Al_2O_3), for example, deposited by ALD.

The layer **37** having photodiodes **38** formed therein may comprise small molecules, oligomers, or polymers. These may be organic or inorganic materials. Layer **37** may comprise an ambipolar semiconductor material, or a mixture of an N-type semiconductor material and of a P-type semiconductor material, for example in the form of stacked layers or of an intimate mixture at a nanometer scale to form a bulk heterojunction. The thickness of layer **37** may be in the range from 50 nm to 2 μm, for example, in the order of 500 nm.

Example of P-type semiconductor polymers capable of forming layer **37** are poly(3-hexylthiophene) (P3HT), poly[N-9'-heptadecanyl-2,7-carbazole-alt-5,5-(4,7-di-2-thienyl-2',1',3'-benzothiadiazole)] (PCDTBT), poly[(4,8-bis-(2-ethylhexyloxy)-benzo[1,2-b;4,5-b']dithiophene)-2,6-diyl-alt-(4-(2-ethylhexanoyl)-thieno[3,4-b]thiophene))-2,6-diyl] (PBDTTT-C), poly[2-methoxy-5-(2-ethyl-hexyloxy)-1,4-phenylene-vinylene] (MEH-PPV), or poly[2,6-(4,4-bis-(2-ethylhexyl)-4H-cyclopenta[2,1-b;3,4-b']dithiophene)-alt-4,7(2,1,3-benzothiadiazole)] (PCPDTBT).

Examples of N-type semiconductor materials capable of forming layer **37** are fullerenes, particularly C60, [6,6]-phenyl-C_{61}-methyl butanoate ([60]PCBM), [6,6]-phenyl-C_{71}-methyl butanoate ([70]PCBM), perylene diimide, zinc oxide (ZnO), or nanocrystals enabling to form quantum dots.

When they are present, the thickness of each interface layer may be in the range from 0.1 nm to 1 μm. One of the interface layers may be made of cesium carbonate ($CsCO_3$), of metal oxide, particularly of zinc oxide (ZnO), or of a mixture of at least two of these compounds. One or the interface layers may comprise a self-assembled monomolecular layer or a polymer, for example, (polyethyleneimine, ethoxylated polyethyleneimine, poly[(9,9-bis(3'-(N,N-dimethylamino)propyl)-2,7-fluorene)-alt-2,7-(9,9-dioctylfluorene)]. The other interface layer may be made of copper oxide (CuO), of nickel oxide (NiO), of vanadium oxide (V_2O_5), of magnesium oxide (MgO), of tungsten oxide (WO_3), or of a mixture of at least two of these compounds.

Active regions **54** may be made of polysilicon, particularly low-temperature polycrystalline silicon (LTPS), of amorphous silicon (aSi), of zinc-gallium-indium (IGZO), of polymer, or comprise small molecules used in known fashion for the forming of organic thin film transistors (OTFT).

According to an embodiment, layer **84** may be totally made of a material absorbing at least for the wavelengths to be angularly filtered. Layer **84** may be made of colored resin, for example, a colored or black SU-8 resin. As an example, layer **84** may be made of a black resin absorbing in the visible range and in near infrared. Openings **86** may be filled with air or filled with a material at least partially transparent to the radiation detected by photodetectors **38**, for example polydimethylsiloxane (PDMS). As a variant, openings **86** may be filled with a partially absorbing material in order to chromatically filter the rays angularly filtered by angular filter **82**. Angular filter **82** may then further play the role of a colored filter. This enables to decrease the thickness of the system as compared with the case where a colored filter different from angular filter **82** would be present. The partially absorbing filling material may be a colored resin or a colored plastic material such as PDMS. The filling material of openings **86** may be adapted to have a refraction index matching with the layers in contact with angular filter **82** or to rigidify the structure and improve the mechanical resistance of angular filter **82**.

When microlenses **92** are present, microlenses **92** may be made of silica, of polymethyl methacrylate (PMMA), of positive resist, of PET, of PEN, of COP, of a mixture of polydimethylsiloxane (PDMS) and silicone, or of epoxy resin. Microlenses **14** may be formed by flowing of resist blocks. Microlenses **14** may further be formed by molding on a layer of PET, PEN, COP, PDMS/silicone or epoxy resin.

Bonding layer **94** may be obtained from an optically clear adhesive (OCA), particularly a liquid optically clear adhesive (LOCA), or a material having a low refraction index, or an epoxy/acrylate glue, or a film of a gas or of a gaseous mixture, for example, air. Preferably, when bonding layer **94** follows the shape of microlenses **92**, layer **94** is made of a material having a low refraction index, lower than that of the material of microlenses **92**. Layer **94** may be made of a filling material which is a non-adhesive transparent material. According to another embodiment, layer **94** corresponds to a film having the array of microlenses **92** applied thereto, for example, an OCA film. In this case, the contact area between layer **94** and microlenses **92** may be decreased, for example, limited to the tops of the microlenses. Layer **94** may then be made of a material having a higher refraction index than in the case where layer **94** follows the shape of microlenses **96**.

According to the considered materials, the method of forming at least certain layers of the image sensor may correspond to a so-called additive process, for example, by direct printing of the material forming the organic layers at the desired locations, particularly in sol-gel form, for example, by inkjet printing, photogravure, silk-screening, flexography, spray coating, or drop casting. According to the considered materials, the method of forming the layers of the image sensor may correspond to a so-called subtractive method, where the material forming the organic layer is deposited all over the structure and where the non-used portions are then removed, for example, by photolithography or laser ablation. Methods such as spin coating, spray coating, heliography, slot-die coating, blade coating, flexography, or silk-screening, may in particular be used. When the layers are metallic, the metal is for example deposited by evaporation or by cathode sputtering over the entire support and the metal layers are delimited by etching.

Advantageously, at least some of the layers of the image sensor may be formed by printing techniques. The materials of the previously-described layers may be deposited in liquid form, for example, in the form of conductive and semiconductor inks by means of inkjet printers. "Materials in liquid form" here also designates gel materials capable of being deposited by printing techniques. Anneal steps may be provided between the depositions of the different layers, but it is possible for the anneal temperatures not to exceed 150° C., and the deposition and the possible anneals may be carried out at the atmospheric pressure.

FIGS. **12** to **16** are cross-section views of structures obtained at successive steps of an embodiment of a method of manufacturing the image sensor **80** shown in FIG. **5**, comprising the following successive steps:

a) forming of substrate **32**, for example comprising a stack of two layers **102**, **104** (FIG. **12**);

b) deposition of a layer of colored resin **84** on substrate **32**, having a thickness substantially equal to height h (FIG. **13**);

c) printing of the patterns of openings **86** in resin layer **84** by photolithography and development of the resin layer to form openings **86** (FIG. **14**);

d) filling of openings **86** (FIG. **15**);

e) forming of intermediate layer **33** (FIG. **16**);

f) forming of stack **34** with transistors (FIG. **17**); and

g) forming of the stack **35** of the layers associated with the photodiodes (FIG. **18**).

The final steps of the method particularly comprise the application of coating **44** and of layer **42** of adhesive material.

An embodiment of a method of manufacturing the image sensor **95** shown in FIG. **10** comprises the steps previously described in relation with FIGS. **12** to **18**, with the difference that steps b), c), and d) are carried out after step f). An advantage of the methods of manufacturing image sensors **80** and **95** is that the opaque layer **84** of angular filter **82** is not deposited in contact with layer **37**, the solvent used for the deposition of opaque layer **84** being capable of degrading layer **37**.

An embodiment of a method of manufacturing the image sensor **100** shown in FIG. **11** comprises the steps previously-described in relation with FIGS. **12** to **18**, with the difference that steps b), c) and d) are carried out after step g) and before the application of coating **44** and of layer **42** of adhesive material. An advantage of the methods of manufacturing image sensors **80**, **95**, and **100** is that the opaque layer **84** of angular filter **82** is not deposited in contact with coating **44**, since the steps of forming of openings **86** may degrade coating **44**.

Various embodiments and variants have been described. Those skilled in the art will understand that certain features of these various embodiments and variants may be combined, and other variants will occur to those skilled in the art. In particular, the embodiments of filter **82** shown in FIGS. **6**, **7** **8**, and **9** may be implemented with any of the image sensors shown in FIGS. **5**, **10**, and **11**. Finally, the practical implementation of the embodiments and variants described herein is within the capabilities of those skilled in the art based on the functional indications provided hereinabove.

The invention claimed is:

1. An image sensor comprising:

organic photodetectors;

an angular filter less than 20 μm away from the photodetectors; and

a surface intended to receive a radiation, said photodetectors being configured to detect said radiation, the angular filter covering the organic photodetectors and being configured to block the rays of said radiation having an incidence relative to a direction orthogonal to the surface greater than a threshold and to give way to rays of said radiation having an incidence relative to a direction orthogonal to the surface smaller than the threshold,

wherein the angular filter comprises a layer opaque to said radiation and an array of openings formed in the layer, the openings being filled with air or with a material at least partially transparent to said radiation, and

wherein the openings are arranged in rows and in columns, a pitch between adjacent openings of a same row or of a same column varying from 10 μm to 60 μm.

2. The image sensor according to claim **1**, wherein, for each opening, a ratio of a height of the opening, measured perpendicularly to the surface, to a width of the opening, measured parallel to the surface, varies from 1 to 10.

3. The image sensor according to claim **1**, further comprising lenses covering the openings.

4. The image sensor according to claim **1**, further comprising a substrate, a first stack of layers comprising thin-film transistors, and a second stack of layers comprising the photodetectors.

5. The image sensor according to claim **4**, wherein the angular filter is located in the substrate, between the substrate and the first stack, in the first stack, or between the first stack and the second stack.

6. The image sensor according to claim **4**, wherein the photodetectors are coupled to the transistors of the first stack by vias crossing the angular filter.

7. The image sensor according to claim **4**, further comprising an encapsulation film tight to oxygen and to humidity covering the photodetectors and wherein the angular filter covers the photodetectors, on the side of the photodetectors opposite to the first stack, between the photodetectors and the encapsulation film.

8. The image sensor according to claim **1**, wherein the photodetectors comprise organic photodiodes.

9. An image sensor comprising:

organic photodetectors;

an angular filter less than 20 μm away from the photodetectors; and

a surface intended to receive a radiation, said photodetectors being configured to detect said radiation, the angular filter covering the organic photodetectors and being configured to block the rays of said radiation having an incidence relative to a direction orthogonal to the surface greater than a threshold and to give way to rays of said radiation having an incidence relative to a direction orthogonal to the surface smaller than the threshold,

wherein the angular filter comprises a layer opaque to said radiation and an array of openings formed in the layer, the openings being filled with air or with a material at least partially transparent to said radiation, and

wherein a height of each opening, measured along a direction orthogonal to the surface, varies from 1 μm to 1 mm.

10. An image sensor comprising:

organic photodetectors;

an angular filter less than 20 μm away from the photodetectors; and

a surface intended to receive a radiation, said photodetectors being configured to detect said radiation, the angular filter covering the organic photodetectors and being configured to block the rays of said radiation having an incidence relative to a direction orthogonal to the surface greater than a threshold and to give way to rays of said radiation having an incidence relative to a direction orthogonal to the surface smaller than the threshold,

wherein the angular filter comprises a layer opaque to said radiation and an array of openings formed in the layer, the openings being filled with air or with a material at least partially transparent to said radiation, and

wherein a width of each opening, measured parallel to the surface, varies from 5 μm to 30 μm.

11. A method of manufacturing an image sensor comprising:

forming organic photodetectors;

forming an angular filter less than 20 μm away from the photodetectors; and

forming a surface intended to receive a radiation,

wherein said forming of said organic photodetectors includes configuring said organic photodetectors to detect said radiation, and

wherein said forming of said angular filter comprises:

covering said organic photodetectors with said angular filter;

configuring said angular filter to block said rays of said radiation having an incidence relative to a direction orthogonal to said surface greater than a threshold and to give way to rays of said radiation having an incidence relative to a direction orthogonal to said surface smaller than the threshold;

forming a layer opaque to said radiation;

forming an array of openings in said layer;

filling the openings with air or with a material at least partially transparent to said radiation;

arranging the openings in rows and in columns; and

varying a pitch between adjacent openings of a same row or of a same column from 10 μm to 60 μm.

12. The method according to claim **11**, wherein, for each opening, varying a ratio of a height of the opening, measured perpendicularly to the surface, to a width of the opening, measured parallel to the surface, from 1 to 10.

13. The method according to claim **11**, further comprising forming lenses covering the openings.

14. The method according to claim **11**, further comprising forming a substrate, a first stack of layers comprising thin-film transistors, and a second stack of layers comprising the photodetectors.

15. The method according to claim **14**, wherein the angular filter is formed in the substrate, between the substrate and the first stack, in the first stack, or between the first stack and the second stack.

16. The method according to claim **14**, wherein the photodetectors are coupled to the transistors of the first stack by vias crossing the angular filter.

17. The method according to claim **14**, further comprising forming an encapsulation film tight to oxygen and to humidity covering the photodetectors and wherein the angular filter covers the photodetectors, on the side of the photodetectors opposite to the first stack, between the photodetectors and the encapsulation film.

18. The method according to claim **11**, wherein the photodetectors comprise organic photodiodes.

19. A method of manufacturing an image sensor comprising:

forming organic photodetectors;

forming an angular filter less than 20 μm away from the photodetectors; and

forming a surface intended to receive a radiation,

wherein said forming of said organic photodetectors includes configuring said organic photodetectors to detect said radiation, and

wherein said forming of said angular filter comprises:

covering said organic photodetectors with said angular filter;

configuring said angular filter to block said rays of said radiation having an incidence relative to a direction orthogonal to said surface greater than a threshold and to give way to rays of said radiation having an incidence relative to a direction orthogonal to said surface smaller than the threshold;

forming a layer opaque to said radiation;

forming an array of openings in said layer;

filling the openings with air or with a material at least partially transparent to said radiation; and

varying a height of each opening, measured along a direction orthogonal to the surface, from 1 μm to 1 mm.

20. A method of manufacturing an image sensor comprising:

forming organic photodetectors;

forming an angular filter less than 20 μm away from the photodetectors; and

forming a surface intended to receive a radiation,

wherein said forming of said organic photodetectors includes configuring said organic photodetectors to detect said radiation, and

wherein said forming of said angular filter comprises:

covering said organic photodetectors with said angular filter;

configuring said angular filter to block said rays of said radiation having an incidence relative to a direction orthogonal to said surface greater than a threshold and to give way to rays of said radiation having an incidence relative to a direction orthogonal to said surface smaller than the threshold;

forming a layer opaque to said radiation;

forming an array of openings in said layer;

filling the openings with air or with a material at least partially transparent to said radiation; and

varying a width of each opening, measured parallel to the surface, from 5 μm to 30 μm.

* * * * *